DØ Note 4500

Problems with the AFE operation at high rates

A. Bross[1], J. Estrada[1], P. Hasiakos[2], and P. Rubinov[1]

[1]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*

[2]*University of Michigan, Ann Arbor, Michigan 48109*

(Dated: 8th July 2004)

Abstract

In this document we present a list of performance limitations observed in the Analog Front End (AFE) board used for the readout of the VLPC based detectors at DØ . The results of this study indicate that there will be significant tracking performance degradation due to the AFE boards.

I. PEDESTAL VARIATION

The intrinsic noise of front end electronics is usually defined in terms of the RMS spread of the measured values for a fixed input in a given channel. Additional contributions to noise come from variations in the pedestal position, both as a function of time and channel number.

Distribution of pedestal values for several AFEI modules (consisting of 64 channels) are presented in Fig. 1. The distributions here are shown for one tick (or bunch crossing). The distributions have a typical width (RMS) of 0.5 pe. The AFE board allows for only one online zero suppression threshold per module, for this reason, the variation of the pedestal across a module is effectively a noise contribution.

The AFE board also shows pedestal variations as a function of tick (bunch crossing). This is shown in Fig. 2, typical tick-to-tick pedestal variations are also of the order of 0.5 pe. This means that the online zero-suppression threshold, in terms of photoelectrons, is not the same for all the ticks. Some ticks are less efficient than average and others have more noise.

II. SATURATION IN THE FRONT END OF THE SVX CHIP

Another aspect to take into account when considering the performance of the CFT electronics at high rates is the saturation of the front end of the SVX. The front end of the SVX chip only resets between superbunches. If the charge accumulated during the 13 crossings in a superbunch becomes too large, the input of the SVX hits the maximum voltage (determined by the power supply) and will not be sensitive to more charge until the next reset.

This problem has been studied in Ref. [1] and the results of the saturation curve for the SVX are presented in Fig. 3. The curve shows that for a VLPC with an average of 10 pe (Poisson distribution), the signal is reduced by $\approx 10\%$ due to saturation in the SVX chip. This test was performed with a VLPC channel that produces approximately 50,000 electrons for each pe, which means that the saturation of the SVX starts at 80 fC.

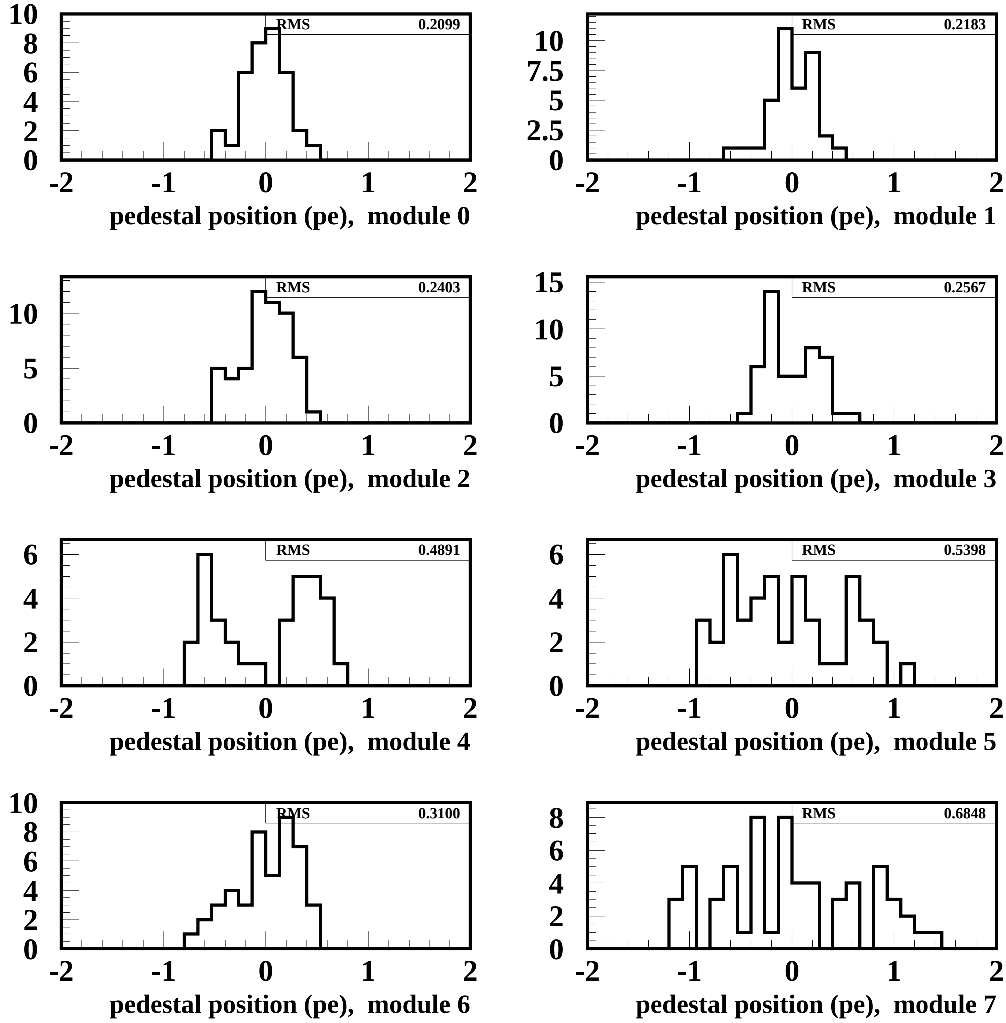

Figure 1: Pedestal position with respect to the mean in the module in units of pe. Each box corresponds to a module of 64 channels. As can be seen from these histograms, a spread of 0.5 pe is typical in an AFE module. (The effect is really in charge, and here was converted to pe just to simplify the comparison with our signal.)

III. DISCRIMINATOR CROSSTALK TO THE ANALOG SIGNAL

Another effect seen in AFE board is the extra noise added to the ADC spectrum by the discriminators firing in the same AFE module (MCM). This effect has been observed in the experiment [3] but was studied in more detail with an AFE board in the 4 cassette test cryostat. The VLPC was illuminated with a fixed amount of light, corresponding to approximately 1.5 pe, and the discriminator threshold for this module was reduced in order

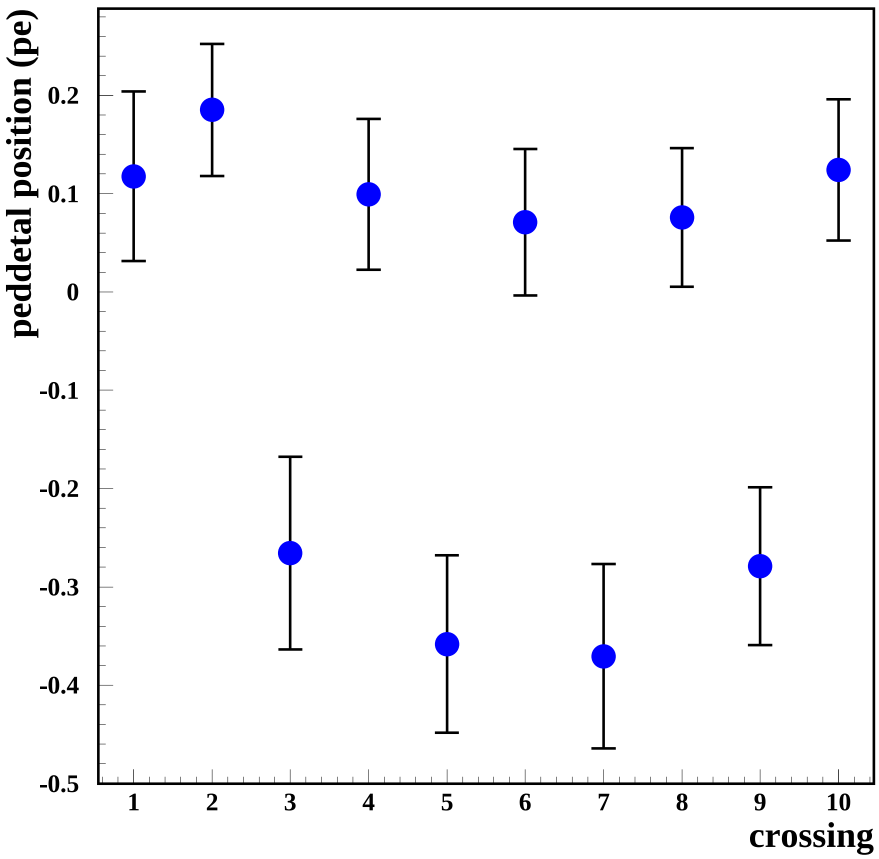

Figure 2: Pedestal position with respect to the mean in the module in units of pe for different ticks. For the AFE module presented here as an example, 0.5 pe pedestal shifts are seen as a function of tick (crossing). (Because of a technical limitation, we could see only 10 crossings out of the 13. Independent tests have shown that the behavior seen here is representative of the 13 crossings.)

to increase the discriminator occupancy. An example of how the ADC spectrum for a given channel changes is shown Fig. 4, with 32% discriminator occupancy for the MCM. In this case the pedestal moves to the left approximately 10 counts (≈1.2 pe) and the ADC resolution is degraded to the point where some individual photopeaks are no longer visible. In Fig. 5 the spectrum for the same channel is shown as a function of discriminator occupancy in the MCM. Another example of a channel changing with increasing discriminator occupancy is shown in Fig. 6; in this case the pedestal moves to the right. A summary of how all the channels in the MCM move with increasing discriminator occupancy can be seen in Fig. 7.

In order to understand the magnitude of this effect in the detector, the occupancy in the CFT at different luminosities was studied [2]. The measured occupancies as a function of

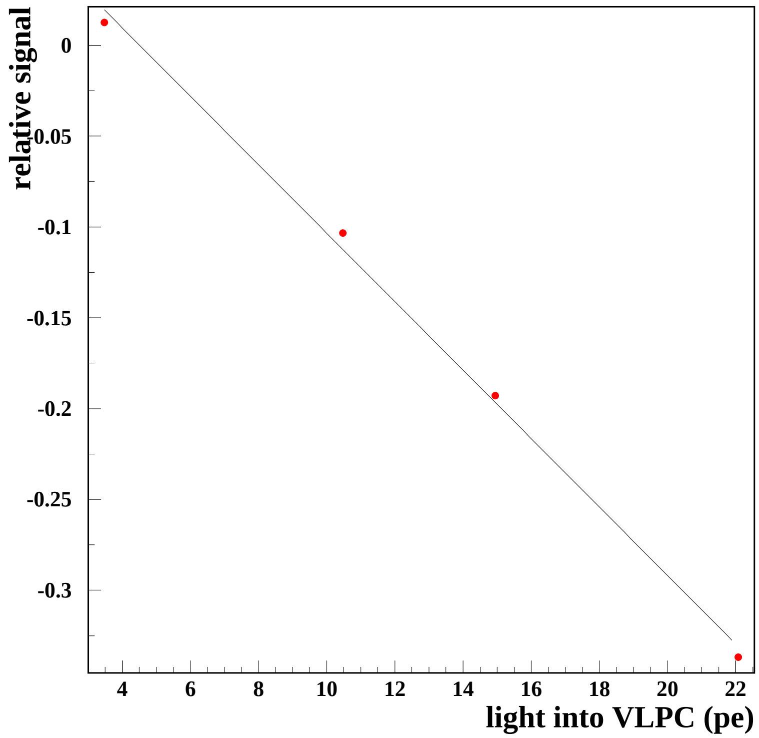

Figure 3: Relative signal, defined as the fractional difference between the signal expected with no saturation and the measured signal, is shown a function of light into the VLPC. A 10% saturation is seen for an average signal of 10 pe (with a Poisson distribution).

luminosities are shown in Fig. 8. For the jet trigger, the inner most layer, has an occupancy of 16% at luminosities of L=40E30. The extrapolation of these occupancies indicate that, for the inner layer of the CFT at L=200E30 we will already be above the level of discriminator occupancies presented in Fig. 7 [2]. The projection presented here is a lower limit because the occupancies presented in Fig. 8 correspond to the layer average. For an MCM that corresponds to a region where a jet has been produced, the real occupancy is somewhat larger.

IV. DISCRIMINATOR CROSSTALK FROM THE PREVIOUS EVENT

The firing of the discriminators does not only affect the pedestals in the analog readout of the AFE, it also affects the pedestals for the digital readout. To test this, two scans were performed in which the discriminator threshold was varied for a fixed LED signal. In the first scan, the LED produced only one pulse every a 21 μs (one pulse per turn). For the second

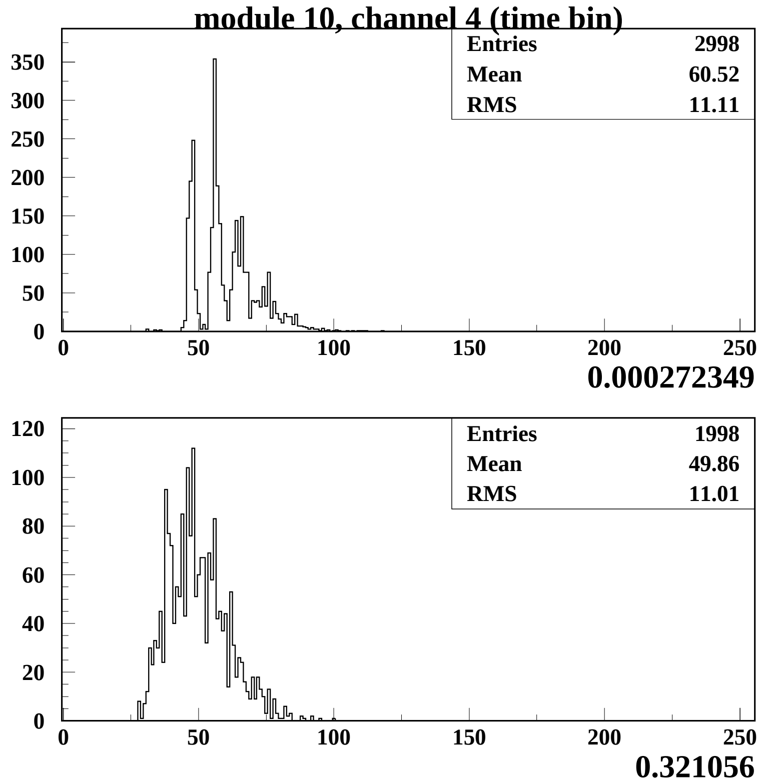

Figure 4: Top: ADC spectrum with $< 1\%$ discriminator occupancy in the MCM. Bottom: ADC spectrum for the same channel, with the same LED illumination, but with a discriminator occupancy for the MCM of 32%. One can see that the firing of the discriminators moves the pedestal to the left and smears the photopeak structure.

scan an LED pulse was produced for every crossing (every 396 nsec). The results of the discriminator occupancy as a function of threshold are shown in Fig. 9. The figure shows that a threshold that gives 20% occupancy for a single pulse, gives only 10% occupancy when pulses are presented in every crossing. This is evidence that the successive firing of the discriminators effectively moves the discriminator threshold by up to 15 DAC counts, which corresponds to 0.6 pe .

In order to check that the firing of the discriminator does not affect the discriminators thresholds of the same tick, we performed two scans with different amplitude for the LED signal. Figure 10 shows that discriminator rates obtained for the two different LED amplitudes, 1.8 and 2.8 pe respectively, are totally consistent with the expectation for a Poisson distribution. These scans also allow us to determine the pe calibration of the threshold

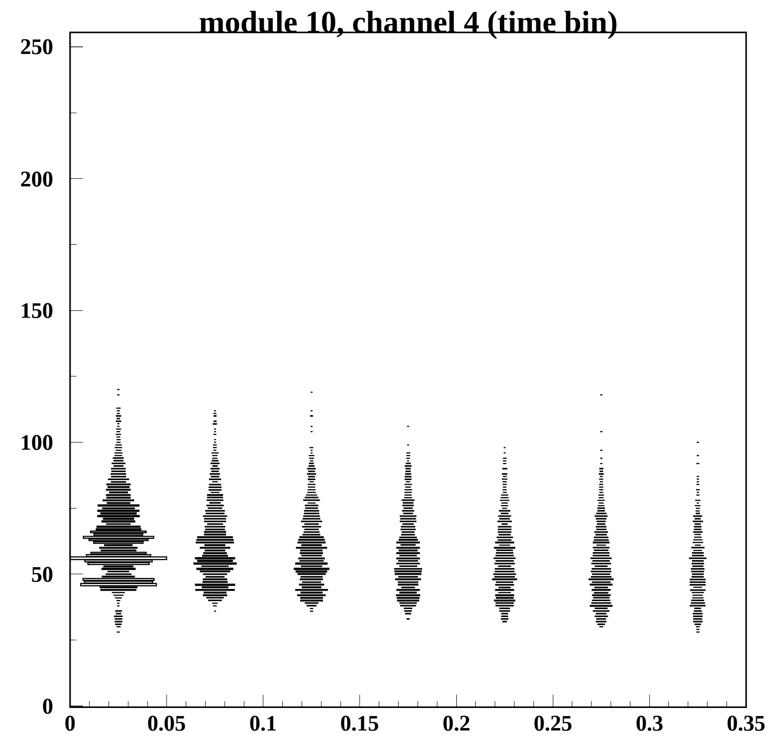

Figure 5: VLPC spectrum of the same channel shown in Fig. 4 is shown in bins of discriminator occupancy on the x-axis. As the discriminator occupancy increases, the spectrum moves to lower ADC values and individual photopeaks eventually eventually are no longer visible.

setting.

V. RATE EFFECT IN THE VLPC

When considering the AFE operation at high luminosities, we need to take into account the known drop in VLPC performance as the rate increases [4].

The studies from which Fig. 8 is derived [2] indicate 8.5% occupancy for zero bias at a luminosity of 40E30 in layer 1 of the CFT (see Fig. 8). This is equivalent to the VLPCs working at a rate of 1.2 MHz-pe (assuming that each hit is 8 pe). This means that the rate for the inner layer will go to 7MHz when the luminosity reaches the expected maximum of 280E30. For this reason we have to take into account the following effects:

- Gain: Based on our measurements at LAB3 [5], the VLPC will suffer a 20% reduction in gain at this rate .

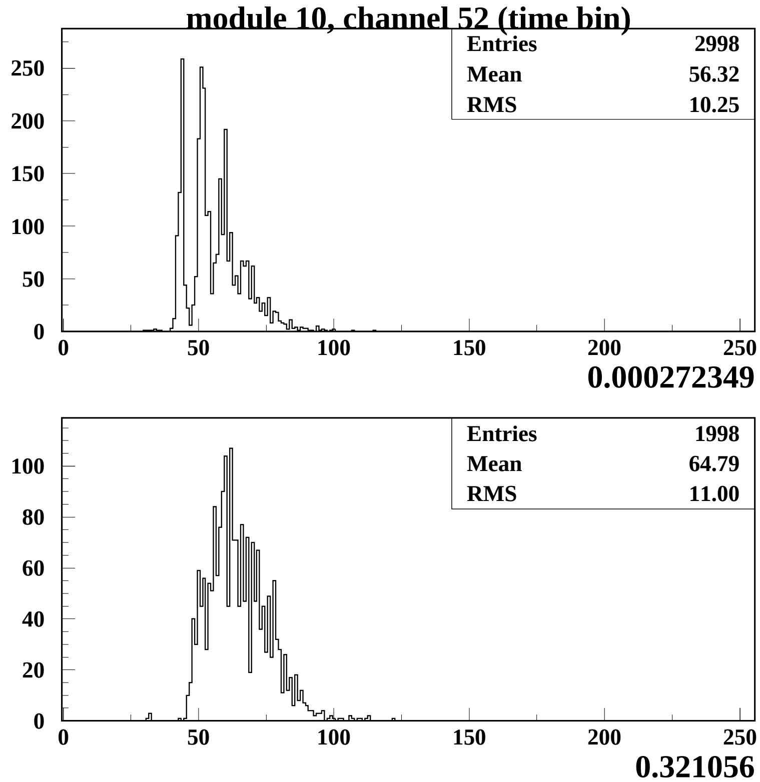

Figure 6: Top: ADC spectrum with $< 1\%$ discriminator occupancy in the MCM. Bottom: ADC spectrum for the same channel, with the same LED illumination, but with a discriminator occupancy for the MCM of 32%. One can see that the firing of the discriminators moves the pedestal to the right and smears the photopeak structure.

- Q.E.: Based on our measurements at LAB3 [5], the VLPC will suffer a 10% reduction in Q.E. at this rate (as long as it is properly rebiased to compensate for rate effects) .

- Fiber aging: due to aging of the fiber, 10% additional reduction in scintillation yield is expected from radiation damage.

The current measurements of light yield in the CFT indicate that we have an average light yield of $\bar{s}_{2003} = 8 \pm 1$ pe for tracks normal to the fibers [6]. Taking into account the drop in performance of the VLPC and the fibers mentioned above, the signal will drop to $\bar{s}_{2006} = 6.5 \pm 0.8$ pe for the highest expected luminosity in the inner layer of the CFT.

The AFE cannot set reliable discriminator thresholds below 12 fC, which corresponds to approximately 1.5 pe. This limit is actually set in charge, and as the gain in the VLPC drops, the threshold will effectively move up. For the highest expected luminosities, the

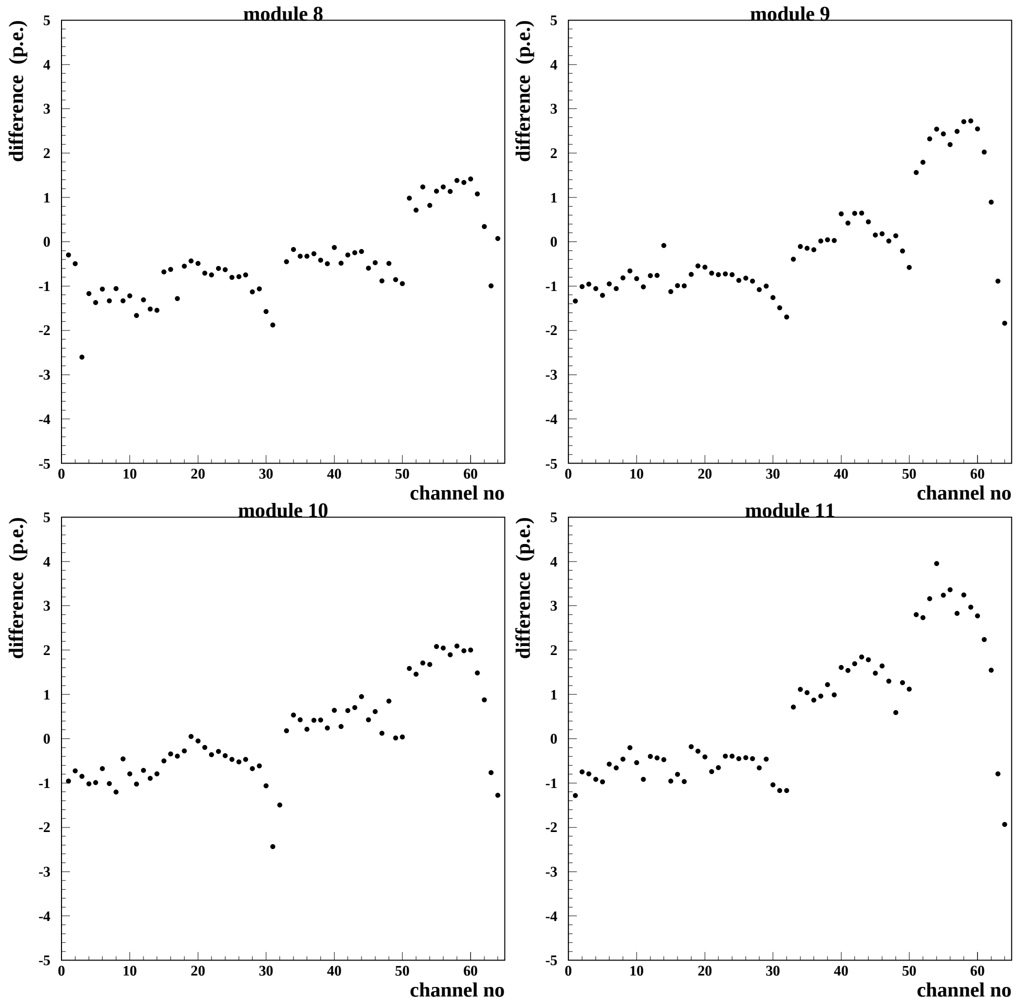

Figure 7: The study shown in Fig. 4 was done for all 8 MCMs in one AFE and the summary of the results is presented here. The difference in the mean of the ADC spectrum between 0% and 32% discriminator occupancy is shown in the y-axis as a function of the channel number x-*axis*. Each box corresponds to one MCM with 64 channels. Typical pedestal shifts of 2 pe are seen, and reach as high as 4 pe in some channels.

minimum reliable thresholds will move to about 2 pe in the inner layer of the CFT.

VI. SUMMARY OF RESULTS AND COMPARISON WITH AFEII

The following points have been identified as major concerns for the operation of the AFE board in the high luminosity environment.

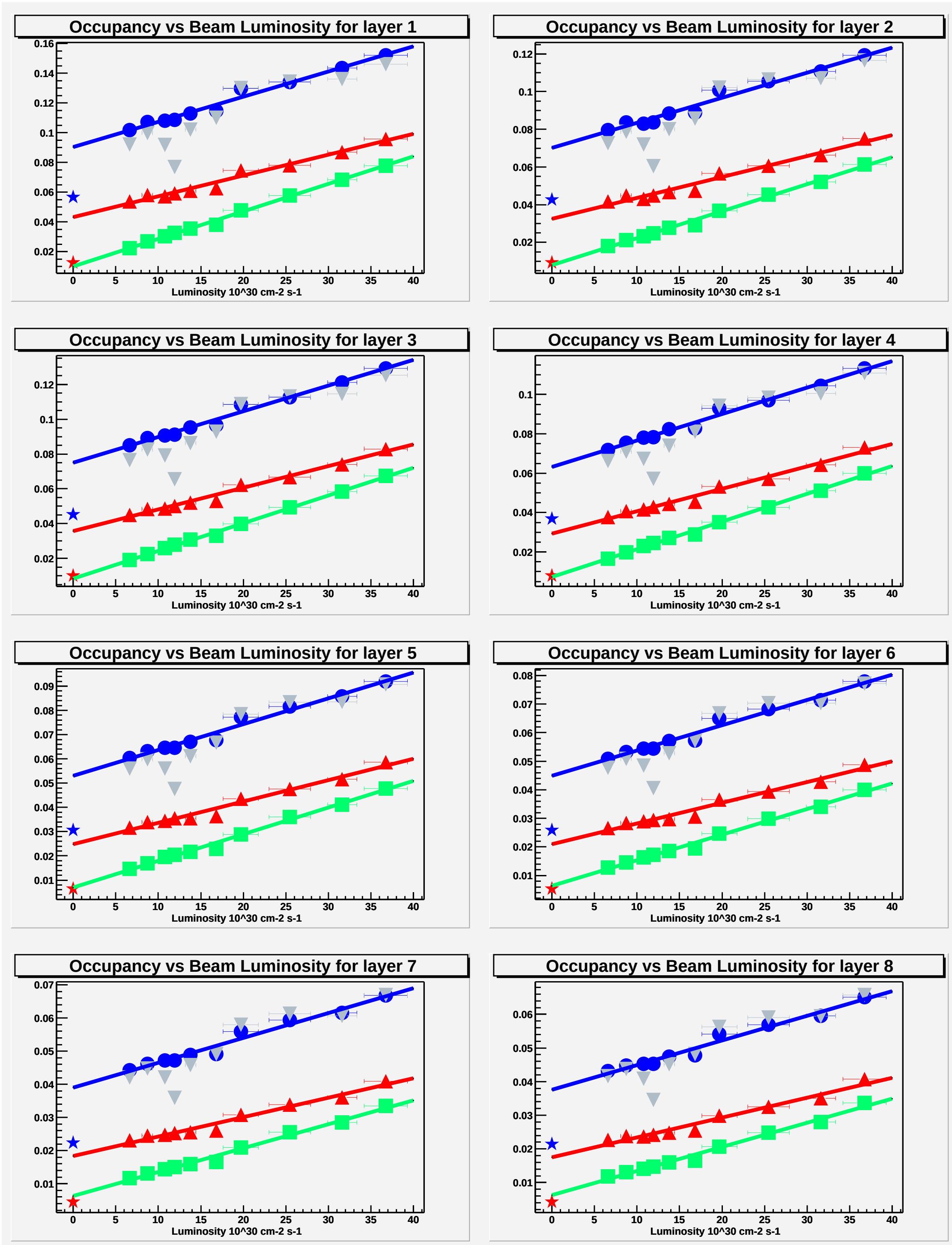

Figure 8: Study of occupancies for the CFT layers as a function of luminosity. Each box corresponds to a different layer of the CFT. The green curve corresponds to the zero-bias trigger, the red curve to the minimum-bias trigger and blue to a jet trigger (JT_45TT) [2].

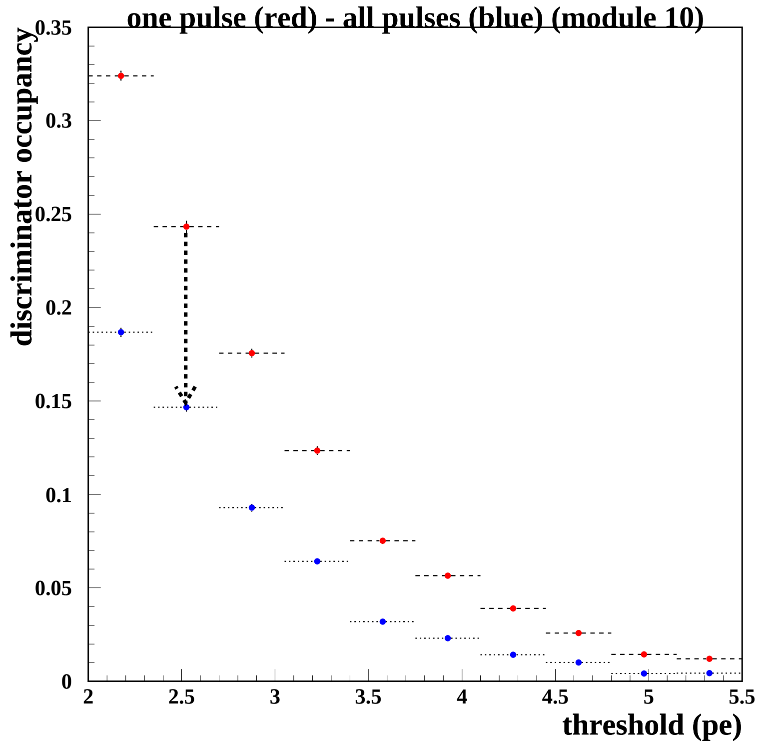

Figure 9: Discriminator occupancy for a fixed LED signal as a function of discriminator threshold. The red points show the result obtained when one pulse was produced by the LED every 21 μs, and the blue points show the results when the same LED pulse is produced for every crossing (every 396 nsec).

- **Effect A**

  The channel-to-channel and tick-to-tick pedestal variations (each of these effects being of about 0.5 pe) introduce extra noise in the VLPC readout.

  Due to this extra noise the hit efficiency for the online threshold drops about 5%. There has not been an evaluation of the performance change in the offline tracking produced by this extra online inefficiency.

  Any channel to channel pedestal variation could be corrected for in AFEII [7] [8]. The FPGA architecture will provide enough flexibility to set independent online thresholds for each channel. The tick dependence of the pedestal is not expected in AFEII (front resets in each crossing), but if something of this kind is seen, we should be able to correct it using the FPGA.

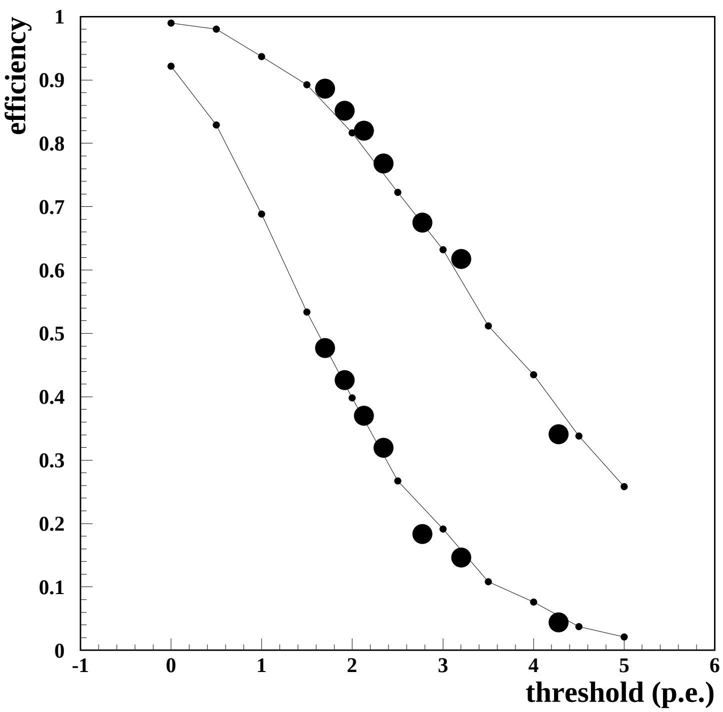

Figure 10: Discriminator occupancy as a function of threshold setting for 1.8 pe light signal from the LED (lower curve) and 3.8 pe light signal from LED (upper curve). The line corresponds to the expected occupancies for simulated VLPC spectrum, and the big circles correspond to the measurements. There is good agreement between the measurements and the expectations.

- **Effect B**

  At L=100E30 the first layer of the CFT will have a zero bias occupancy of $\approx$ 20%, which means that each channel will accumulate an average of 20 pe in each superbunch (assuming 8 pe per hit). Taking into account the SVX saturation, there will be a drop of 20% in the gain of the last crossing in the superbunch.

  The front end of AFEII is resetted in each crossing, there is no saturation of the front end, as seen in AFEI.

- **Effect C**

  As the luminosity increases, the high rate firing of the discriminators will corrupt the analog information. Here we have shown that at 30% discriminator occupancy, one could expect typical pedestal shifts of 1 pe, reaching as high as 4 pe in some cases.

Due to these pedestal shifts, a significant fraction of the readout channels of the CFT (about 1/3) will be less than 90% efficient for offline tracking. The impact of this extra hit inefficiency on tracking reconstruction has not yet been evaluated.

Also due to these pedestal shifts, it will not be possible to use the analog information for charge splitting inside a cluster. This will impact the final position resolution in the CFT tracks. The impact has not been qualitatively evaluated.

Our tests performed with AFEII prototype [9] indicate that the firing of the discriminators will have no effect in the analog readout.

- **Effect D**

The high rate of discriminators firing will also affect the discriminator thresholds. Here we have demonstrated that a threshold shift of 0.6 pe is expected when the discriminator occupancy is approximately 25% (see Fig. 10). This shift introduces a hit inefficiency that will depend on the light yield of the detector. Assuming a light yield of 5.7 pe per hit (consistent with the lower limit of the light yield measured in 2003 and the estimation of the detector performance drop due to VLPC rate effects and aging of scintillating fibers), we get a hit efficiency drop due to this threshold shift from 94.5% to 91%, as shown in Fig. 11.

The effect of the extra hit inefficiency in the L1 track trigger efficiency will depend on the algorithm used for the track reconstruction. A new algorithm will be used for the upgraded track trigger, and the performance of this algorithm as a function hit efficiency is as yet unknown. For this reason we use the current algorithm to evaluate how this extra inefficiency will affect our tracking capabilities at L1. In the current algorithm, the trigger can only reconstruct tracks with no misses (8 hits). Under these conditions, the extra hit inefficiency produces a reduction in tracking efficiency of 77% (from 61% to 47%).

One way to evaluate the impact of this extra L1 tracking inefficiency on DØś physics potential is to consider the impact on the STT trigger. In Ref. [10] a L2 trigger list is presented for Higgs searches. In the case of Zh, associated Higgs production with $Z \to \nu\bar{\nu}$ and $h \to b\bar{b}$, the L2MHT(10)L2STT(tight) trigger term has a quoted efficiency of 59% at a rate of 70 Hz. This efficiency does not take into account the L1

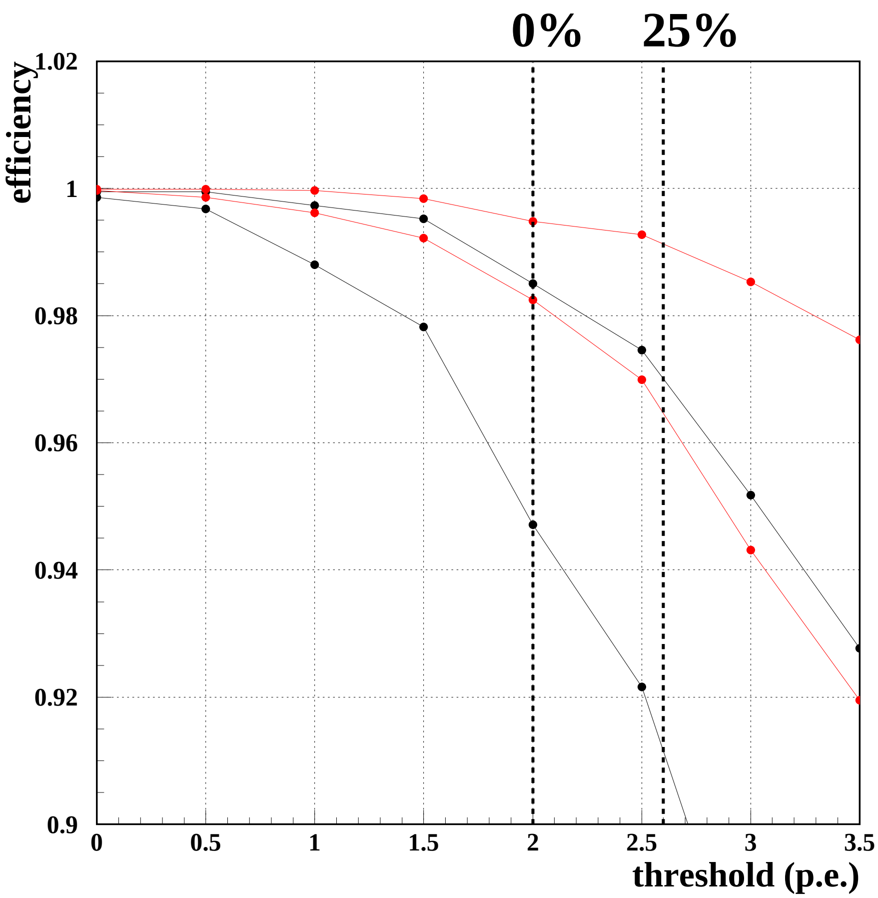

Figure 11: Hit efficiency as a function of threshold setting. The red curves correspond to the high and low limit of the 2003 measured light yield. The black curves correspond to the expected light yield in 2006 for the high and low limits taking into account the performance drop in the detector. The dotted vertical lines show the effective threshold setting for 0% and 25% discriminator occupancy, taking into account discriminator-to-discriminator crosstalk. For the low limit in the 2006 expected light yield curve (with 5.7 pe), the hit efficiency drops from 94.5% to 91% due to the discriminator-to-discriminator crosstalk.

tracking inefficiency from which the L2STT starts. If one assumes no discriminator-to-discriminator crosstalk (61% tracking efficiency), the efficiency for this term is reduced to 42%. If one includes the extra inefficiency due to discriminator-to-discriminator crosstalk, the efficiency for the terms drops to 34%. This means that we will be loosing 20% of our potential Higgs events because of the discriminator-to-discriminator crosstalk.

VII. CONCLUSION

Our efficiency to trigger in Higgs events could drop up to 20% if we keep AFEI.

The analog information coming out of AFEI will become distorted as the luminosity goes up, above luminosities of L=200E30 this information should not be used for tracking. We believe this demonstrates the limitations of AFEI and the need for the replacement of the CFT front end electronics.

As an alternative to this problem, we could drop the analog information and use only the discriminator information for tracking. This will improve the performance of the CFT at high rates, but in this case we will still suffer from the effect discussed in Section IV.

---

[1] P. Hasiakos and J. Estrada, "Saturation of the SVX chip", DØ Note 4495 (2004).

[2] David W.K. Lam and Michael D. Hildreth, "Study of the CDF Occupancy dependence on Beam Luminosity", DØ Note 4499 (2004).

[3] J. Warchol, "CFT Status, AFE PED instabilities", presentation at FTG meeting on 6-22-2004, http://www-d0.hef.kun.nl///fullAgenda.php?ida=a041039. It should be noted that at the time of the presentation there was not a complete understanding of the relation between the observations in the detector, and our observations of discriminator crosstalk, but now we believe that they are the same effect.

[4] A. Bross et al, in "Proceedings of the Workshop on Scintillating Fiber Detectors, SCIFI 97", Notre Dame University, November, 1997, edited by R. Rutchi (American Institute of Physics, Woodbury, NY), p. 332; A. Boss et al., FERMILAB-PUB-04-040-E (2004).

[5] V. Buescher et al., "Testing and characterization of VLPC cassettes", DØ Note 3912 (2001).

[6] Measurements performed by Oana Boeriu (2003).

[7] P. Rubinov and B. Hoeneisen, "Design of the new MCM", DØ Note 3898 (2001).

[8] J. Estrada et al., "MCM II and the Trip chip", DØ Note 4009 (2002); J. Estrada et al., "Characterization of the TriP chip at 132ns using a modified AFE1c board", DØ Note 4076 (2003).

[9] J. Estrada et al, "System tests of the new electronics for the Central Fiber Tracker and Preshower detectors", DØ Note 4233 (2003).

[10] A. Turcot, "A Trigger Strategy for Associated Higgs Boson Production at L = 2E32", DØ Note 4186.